Performance and readiness of TPC for CEPC

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- **Performance of TPC for CEPC TDR**

Motivation: TPC as the main tracker for CEPC

- **TPC as the main tracker detector to satisfy the physics requirements :**
  - **For Higgs run,** W and top running, **no problem** for all TPC readout technologies.
    - Central Tracking **is entrusted to a pad readout TPC detector**.
  - **For high luminosity (2×10^{36}) Z pole run**:
    - Pixelated readout TPC is a good option at **high luminosity** on the circular e+e- collider.
    - The gating will not be possible, so we need an ion back flow suppression without gating R&D (double or triple mesh/mutil-Mesh, graphene membrane...)
    - Some **intense R&D program has to be addressed**.

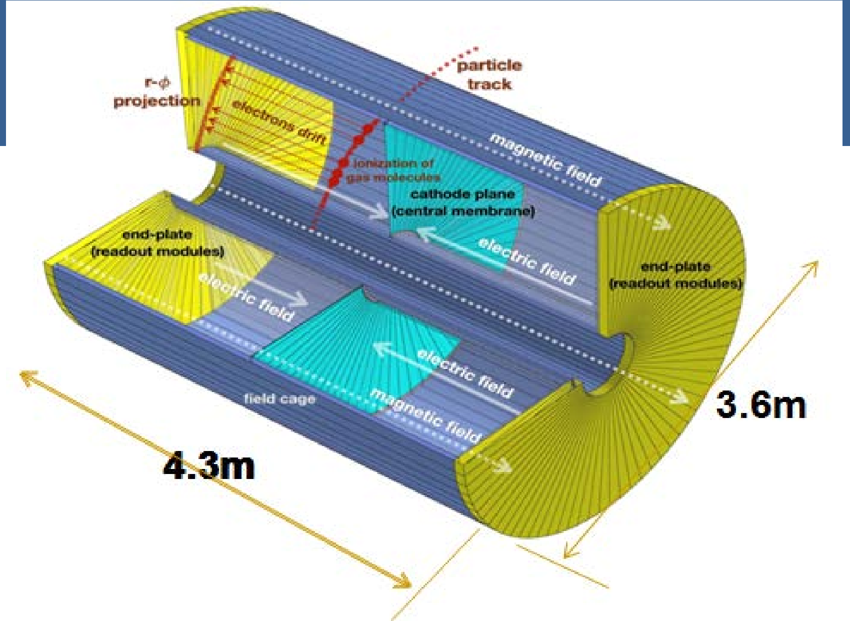
TPC key parameters for Higgs run

Parameters	CEPC CDR	Achievement by Prototype
B-field	3.0T without any E×B effect	1.0T at 5GeV/e-beam
Geometrical parameters	r_{in} r_{out} z 0.6m 1.8m 2.99m	r z 0.8m 0.5m
Solid angle coverage	Up to cosθ ≃ 0.85	/ (OK)
TPC material budget	≃ 0.05 X_0 including outer fieldcage in r < 0.25 X_0 for readout endcaps in z	≃ 0.012 X_0 including outer fieldcage in r < 0.17 X_0 for readout endcaps in z
Number of pads	≃ 8×10^5 of all endcaps	7×4976 of the seven modules
Pad pitch/ NO. of Padrows	≃ 1×6 mm^2 / 200 points per track in rφ	≃ 1×6 mm^2
σ_{point} in rφ	≃ 60 μm for zero drift, ≤ 120 μm overall	≤ 100 μm overall
σ_{point} in rz	≃ 0.4 – 1.4 mm (for zero – full drift)	≃ 0.4 – 0.8 mm (for zero – full drift)
2-hit separation in rφ	≃ 2 mm	< 2 mm
dE/dx resolution	≤ 4 % (Pad readout)	≤ 3.6 % (Pad readout)
Momentum resolution	$\delta(1/p_t) \simeq 0.7\times10^{-4}$/GeV/c (TPC only)	/ (OK)
Ions suppression	IBF×Gain≤ 1	IBF×Gain≤ 1@Gain=2000

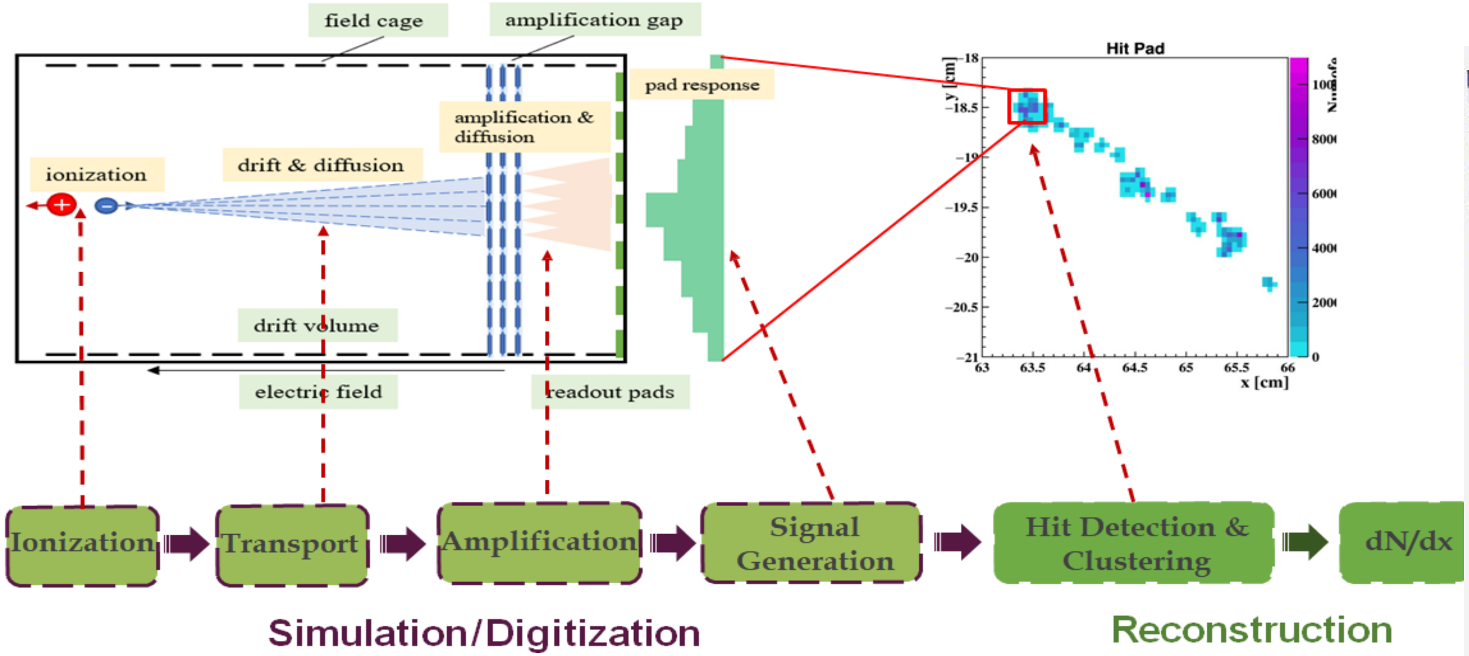
TPC key parameters for Z pole run

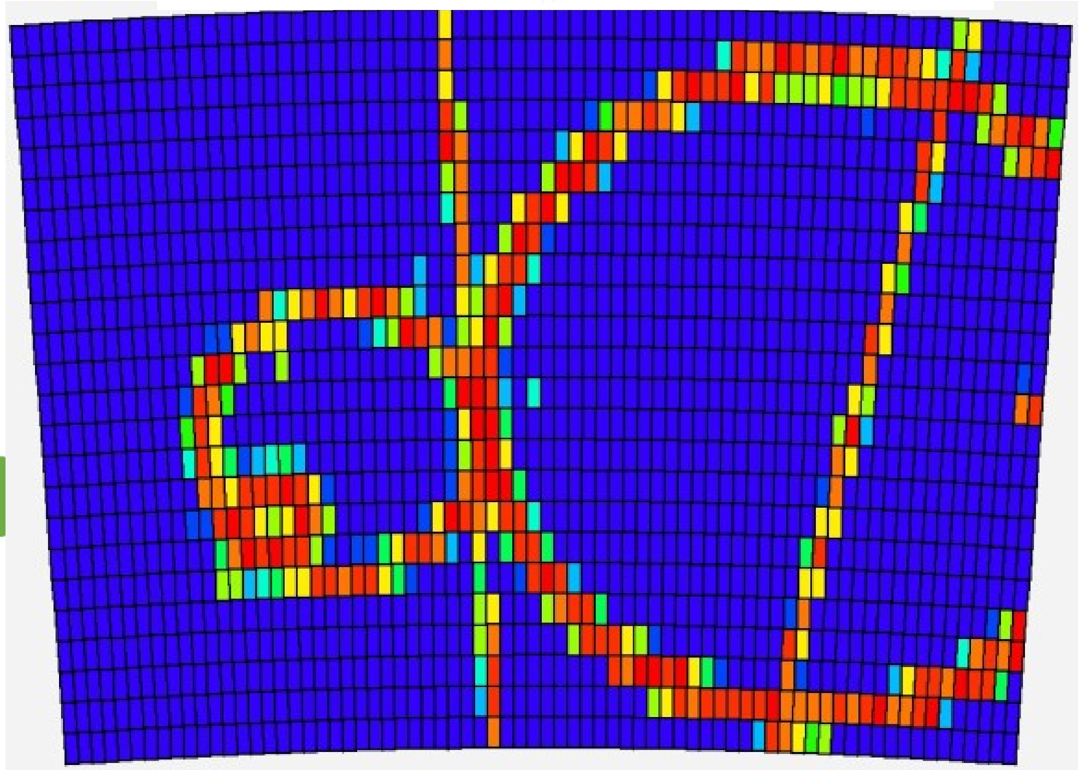
Parameters	CEPC CDR	Achievement by Prototype
B-field	2.0T without any E×B effect	1.0T at 5GeV/e-beam
Geometrical parameters	r_{in} r_{out} z 0.6m 1.8m 2.99m	r z 0.8m 0.5m
Solid angle coverage	Up to cosθ ≃ 0.85	/ (OK)
TPC material budget	≃ 0.05 X_0 including outer fieldcage in r < 0.25 X_0 for readout endcaps in z	≃ 0.012 X_0 including outer fieldcage in r /
Number of pads	≃ 10^9 of all endcaps	2.4cm×9.6cm of the 3 modules
Pad pitch/ NO. of Padrows	/	≃ 55μm ×55μm / (Still R&D)
σ_{point} in rφ	≃ 60 μm for zero drift, ≤ 120 μm overall	≤ 80 μm
σ_{point} in rz	≃ 0.4 – 1.4 mm (for zero – full drift)	/
2-hit separation in rφ	≃ 2 mm	< 0.5mm
dE/dx resolution	≤ 4 % (Pad readout)	≤ 3 % (Pixelated readout) / (Still R&D)
Momentum resolution	$\delta(1/p_t) \simeq 0.7\times10^{-4}$/GeV/c (TPC only)	/
Ions suppression	Primary ions level	/ (Still R&D)

Optimization of Pad readout size



- **Simulation of TPC readout pad size**
  - Framework of the simulation are ready
  - Simulation on going





Cost – TPC

- **TPC cost estimation**
  - Chamber
  - Endplate
  - Electronics
  - Alignment
  - HV
  - Gas system

TPC COST ESTIMATION (Unit: *10K RMB)

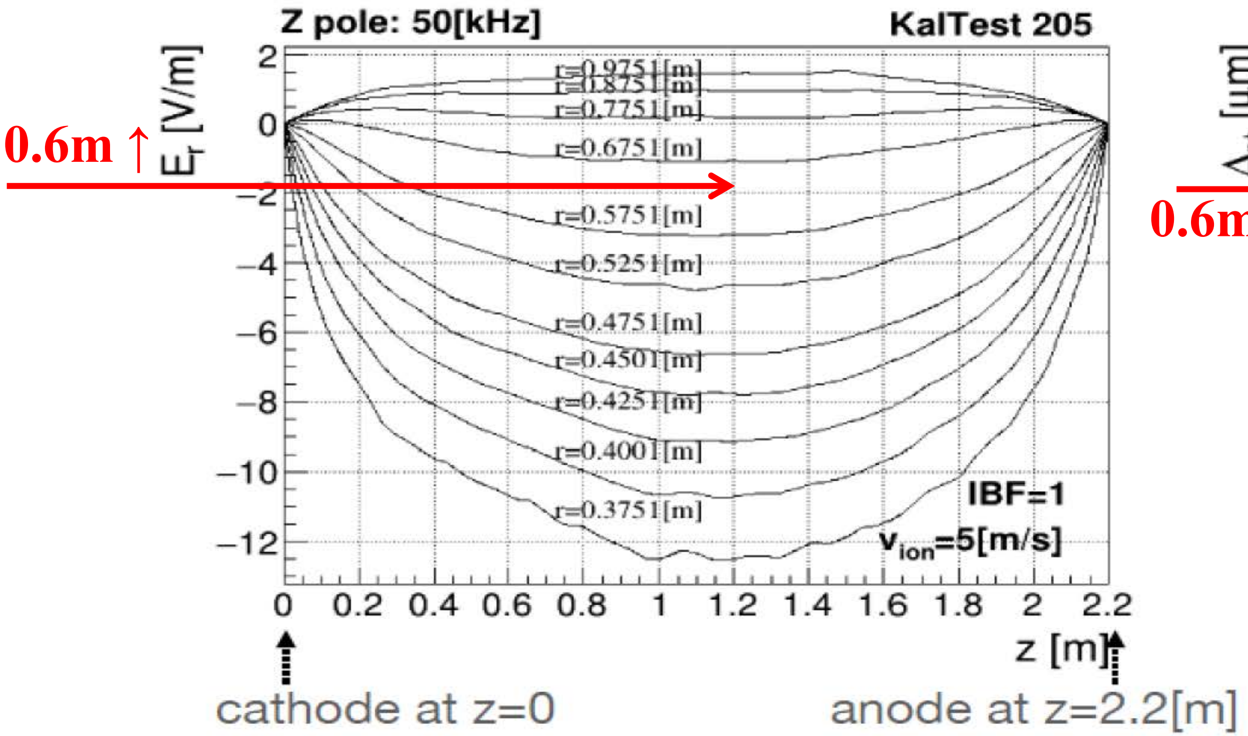
			Detector concept/ Detector items	Unit	Unit cost (RMB)	Quantity	total cost (RMB)
Number			CEPC				
3.2			Time Projection Chamber				18000.00
	3.2.1		**Chamber**				**3600.00**
		3.2.1.1	Fieldcage		1200.00	1	1200.00
		3.2.1.2	Connector		800.00	1	800.00
		3.2.1.3	Barrel		600.00	1	600.00
		3.2.1.4	HV test bef. Assembly		400.00	1	400.00
		3.2.1.5	Support board		600.00	1	600.00
	3.2.2		**Endplate**				**2500.00**
		3.2.2.1	MPGD detector		800.00	1	800.00
		3.2.2.2	Support board		600.00	2	1200.00
		3.2.2.3	Readout bef. Assembly		2.50	200	500.00
	3.2.3		**Electronics**				**10000.00**
		3.2.3.1	FEE ASIC readout		0.012	200000	2400.00
		3.2.3.2	Cables		0.03	50000	1500.00
		3.2.3.3	Optical driver		0.03	50000	1500.00
		3.2.3.4	Optical link, connectors		1.00	500	500.00
		3.2.3.5	DAQ system		0.30	5000	1500.00
		3.2.3.6	Crate and controller		20.00	50	1000.00
		3.2.3.7	Cooling system		1600.00	1	1600.00
	3.2.4		**Alignment and calibration**				**500.00**
		3.2.4.1	Calibration system		500.00	1	500.00
	3.2.5		**HV and Gas system**				**1400.00**
		3.2.5.1	HV and low power		600.000	1	600.00
		3.2.5.2	Gas system		300.00	1	300.00
		3.2.5.3	Slow control system		300.00	1	300.00
		3.2.5.4	Shipping bef. Assembly		200.00	1	200.00

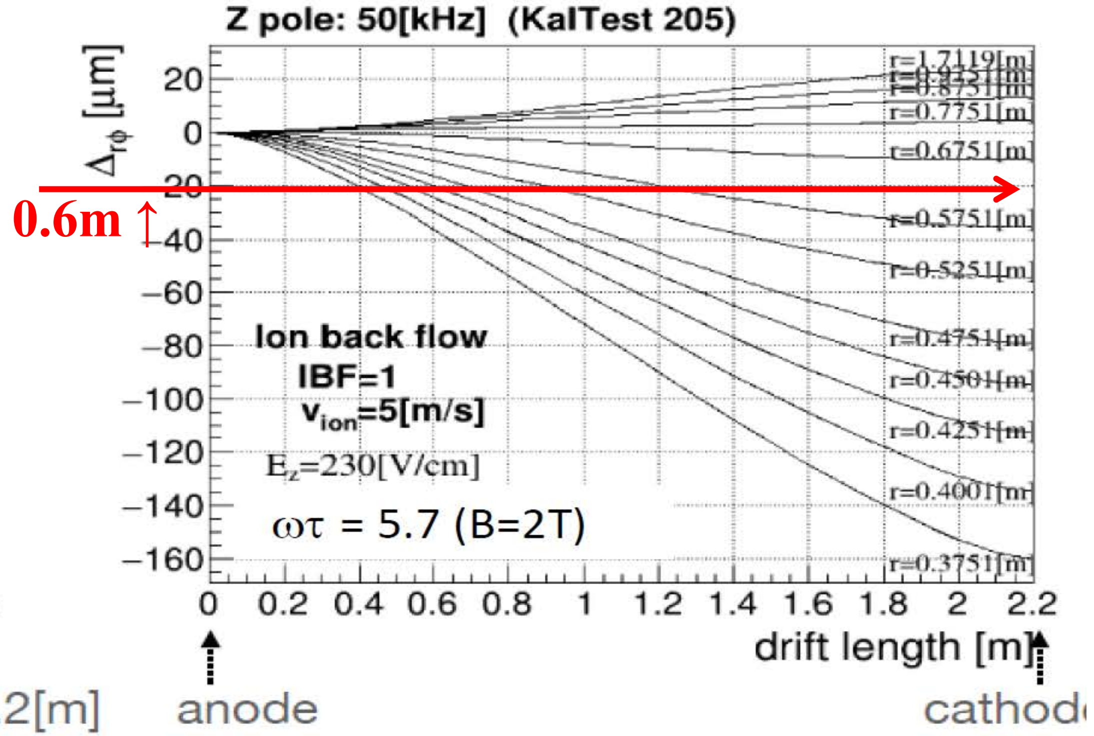
Z pole run: hadronic Z event rate: **50 [kHz]** (toy MC using pythia8)

V_{ion} = 5 [m/s]

IBF*Gain=1

K. Fujii





bin size: (Δz, Δr)=(1[cm], 0.5[cm])

Glitches correspond to hot spots in ρ_{ion}, which seem to be averaged out in Δrϕ

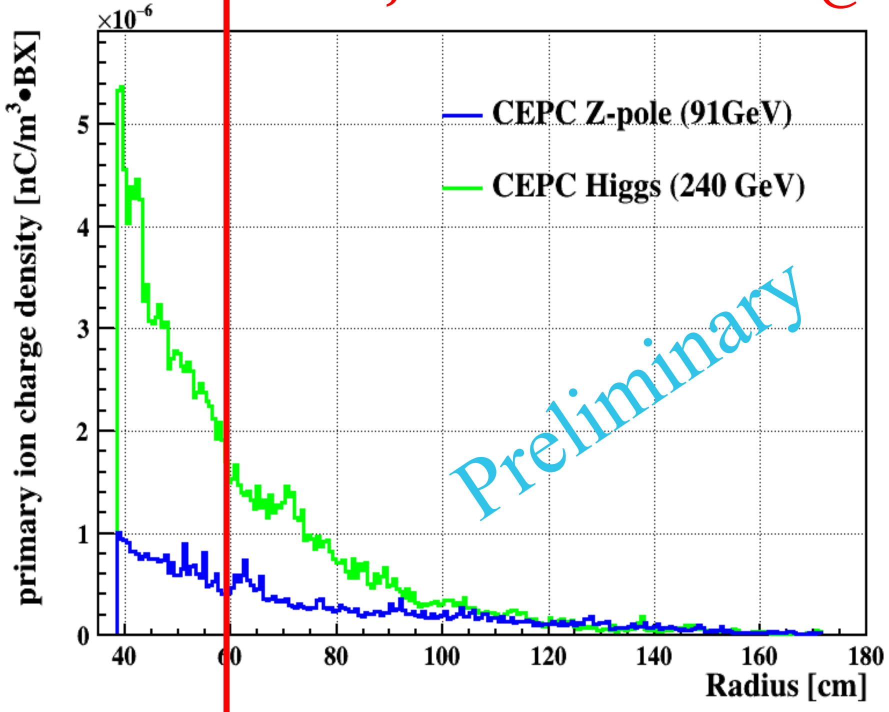
Maximum distortion ~160 [μm] at the innermost region for hadronic Z rate of 50 [kHz]

Ions distortion at Z pole run – background

- **For Higgs run, no problem detector factor for TPC**
- **For Z pole run**
  - **TPC with IBF*Gain=1 at CEPC-91**

    → at best, less or similar space-charge as at ALICE

>0.6m, decreased to 35% @0.3m

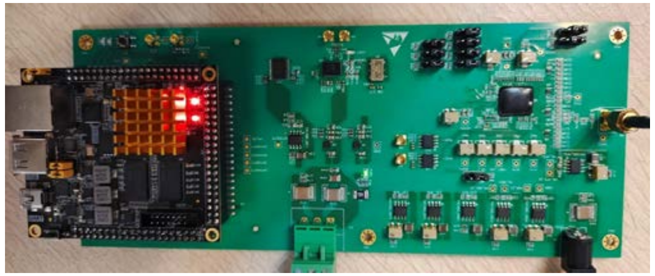


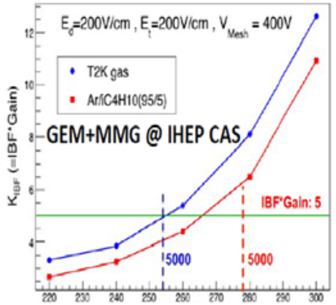
Collider Detector Model	CEPC_v4	CEPC_v4
Beamstrahlung pairs	CEPC Z-pole(91GeV)	CEPC Higgs(240GeV)
BX freq.	1/23 ns	1/680 ns
primary ions/BX	27.37 k	72.36 k
primary ions at any time	5.95×10^{11}	5.32×10^{10}
average primary ρ_{ion} [nC/m^3]	2.43	0.22
max (single BX) [nC/m^3/BX]	1.05×10^{-6}	5.4×10^{-6}
max (steady state) [nC/m^3]	11.4	1.98

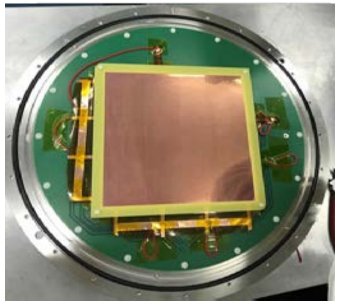
- **Readiness of TPC for CEPC TDR**

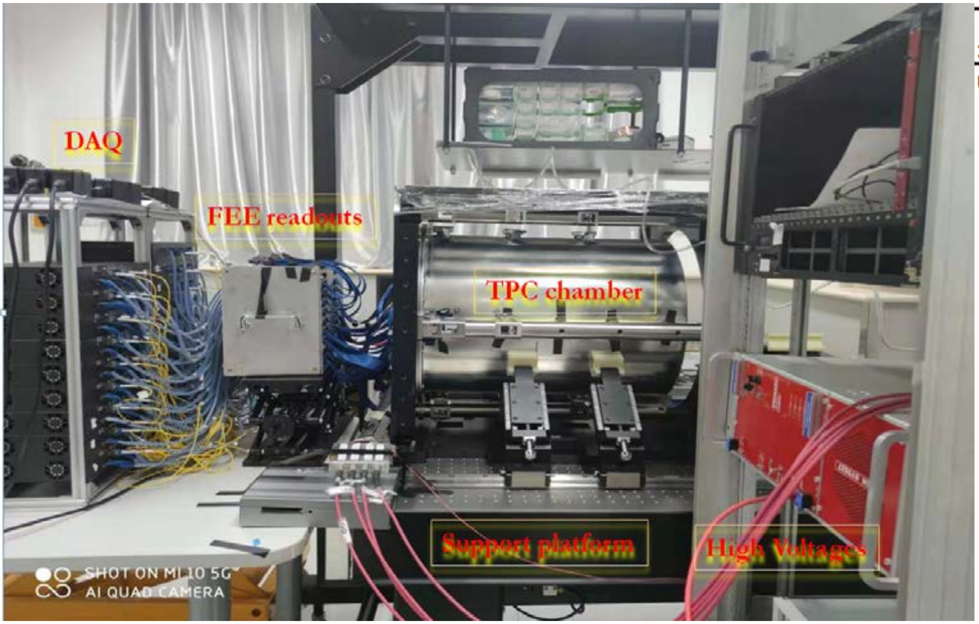
Pad readout TPC – Low power consumption and hybrid readout @IHEP

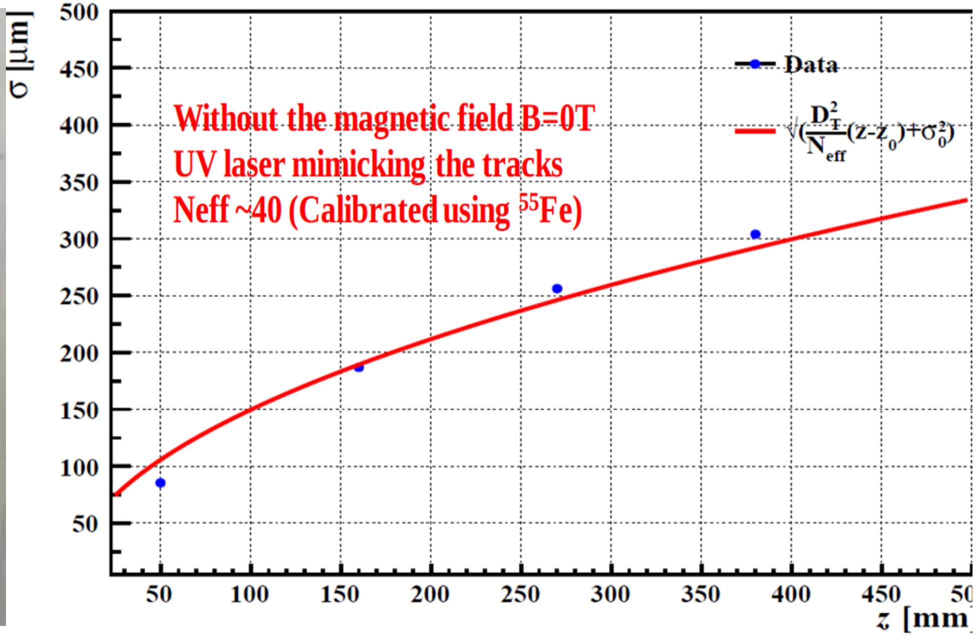
- **Low power consumption ASIC has been developed for TPC readout.**
  - Low power consumption FEE ASIC (**~2.4 mW/ch** including ADC)
- **Hybrid readout module has been developed:**
  - IBF×Gain **~1 at Gain=2000** validation with GEM/MM readout
  - Spatial resolution of **$\sigma_{r\varphi} \leq 100$ μm** by TPC prototype
  - Pseudo-tracks with 220 layers (**same as the actual size of CEPC baseline detector concept**) and dE/dx is about 3.4 ± 0.3%

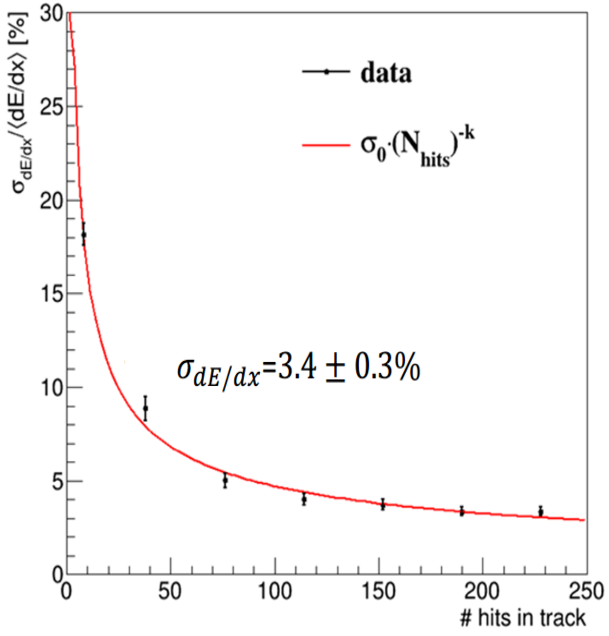








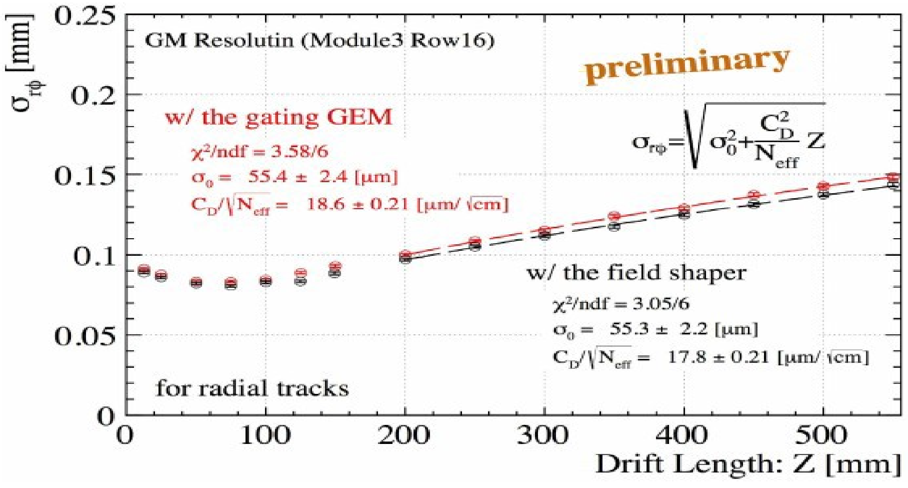


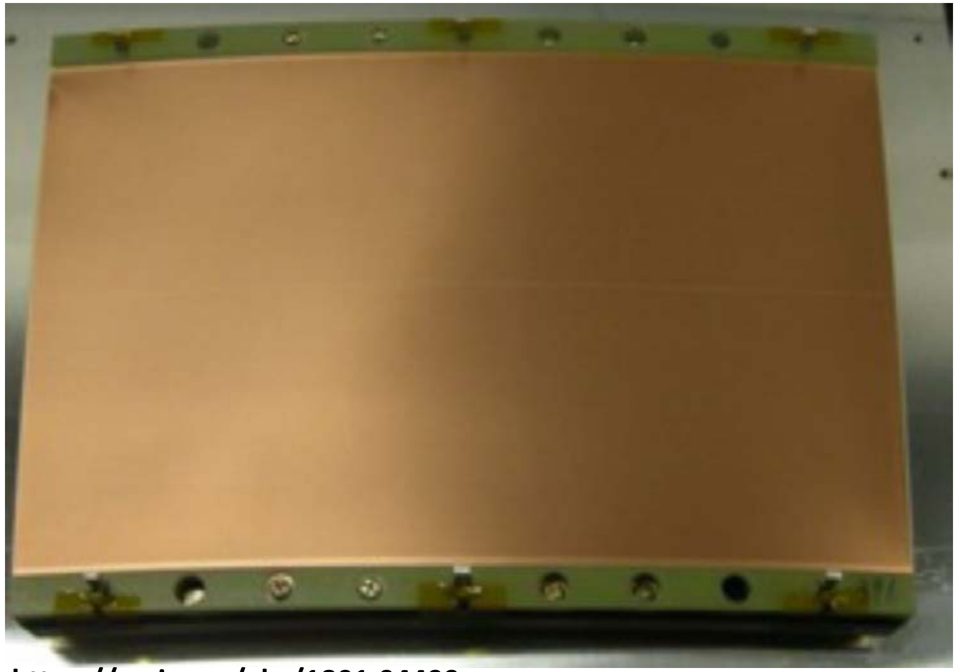


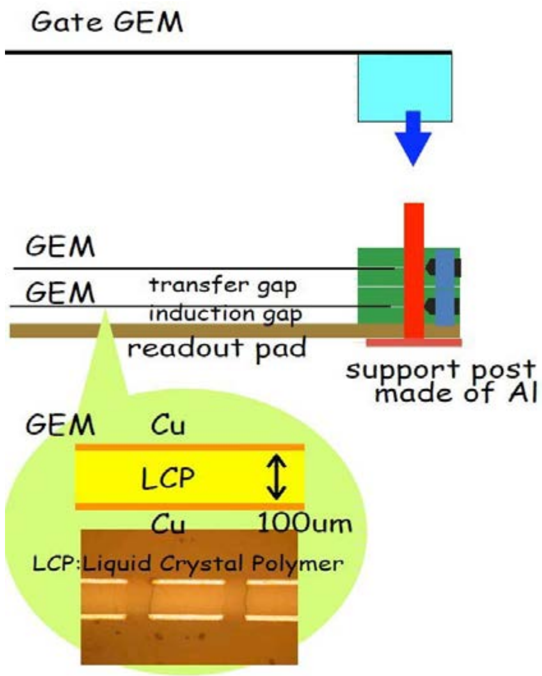
https://doi.org/10.1016/j.nima.2022.167241

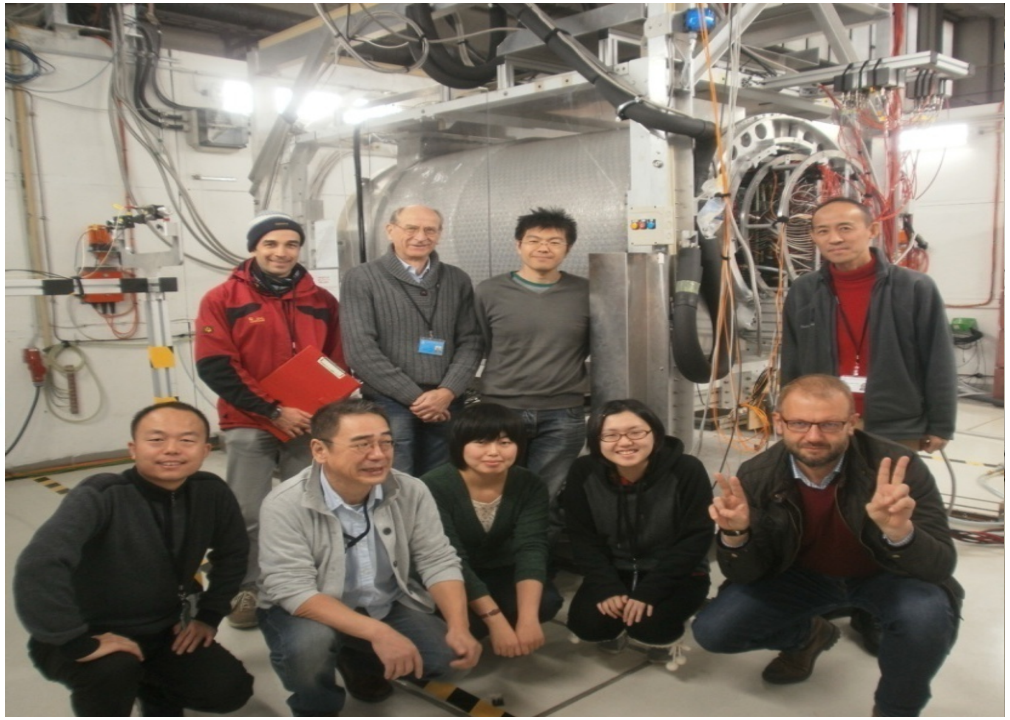
Pad readout TPC technology – GEMs readout @LCTPC

- **TPC prototype have been studied the beam under 1.0T.**
  - GEMs with 100μm LCP insulator
  - Standard GEM from CERN
- Design idea of the GEM Module:
  - **No frame** at modules both sides
  - Spatial resolution of $\sigma_{r\phi} \leq 100$ μm, more stability by the broader arcs at top and bottom





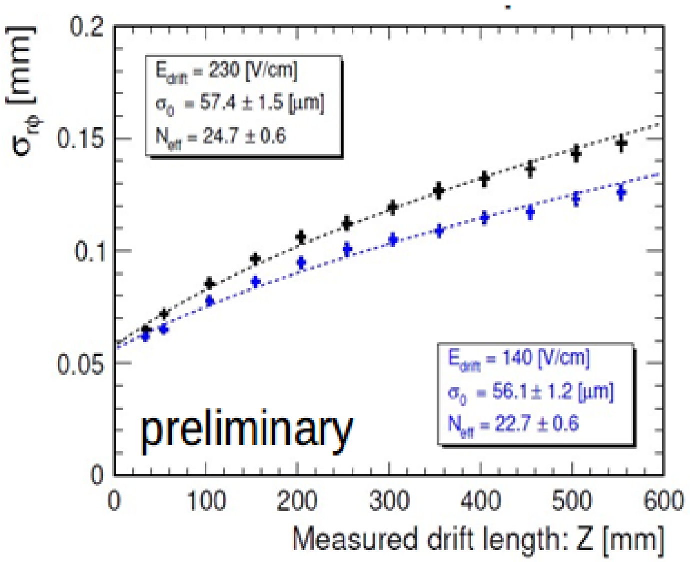


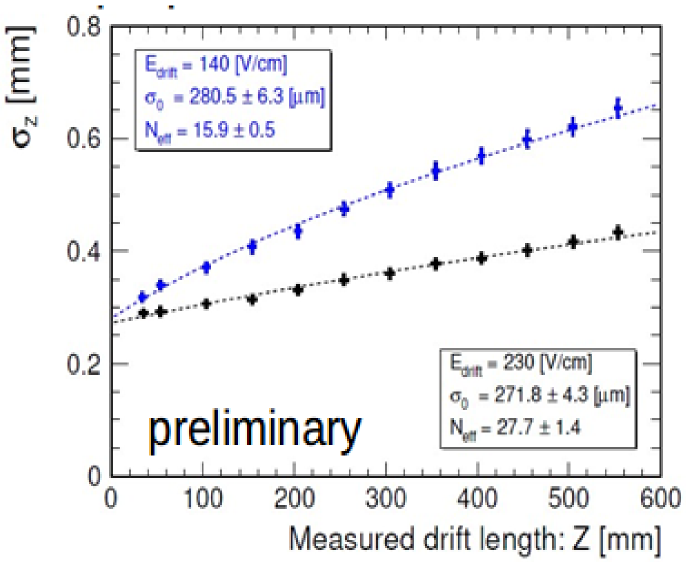


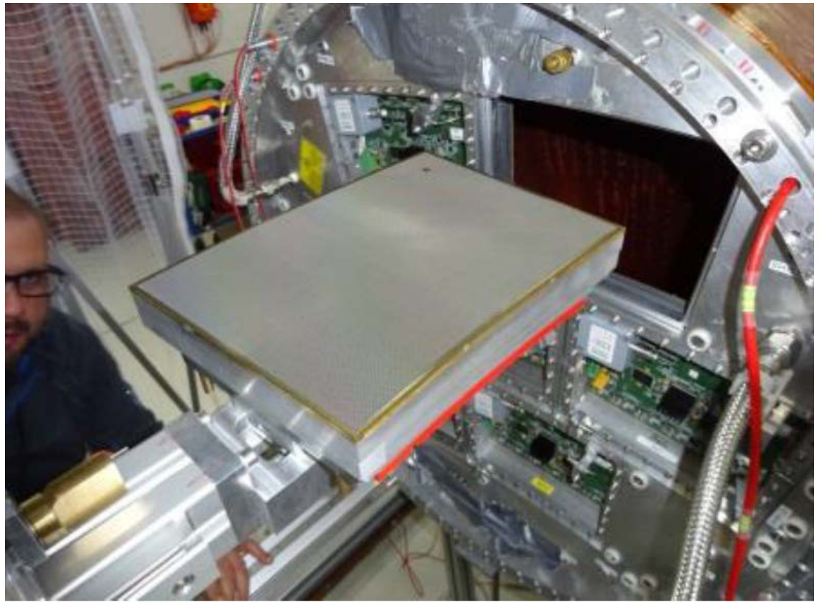
https://arxiv.org/abs/1801.04499

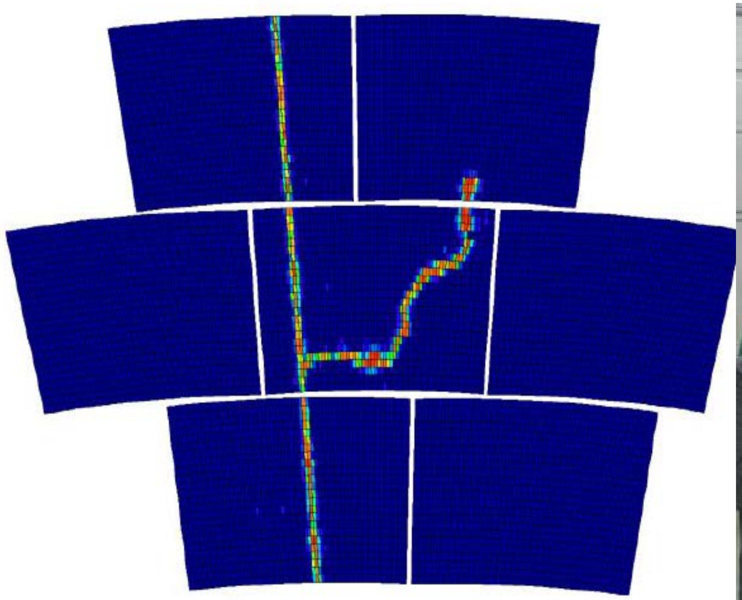
Pad readout TPC technology – Resistive Micromegas readout @LCTPC

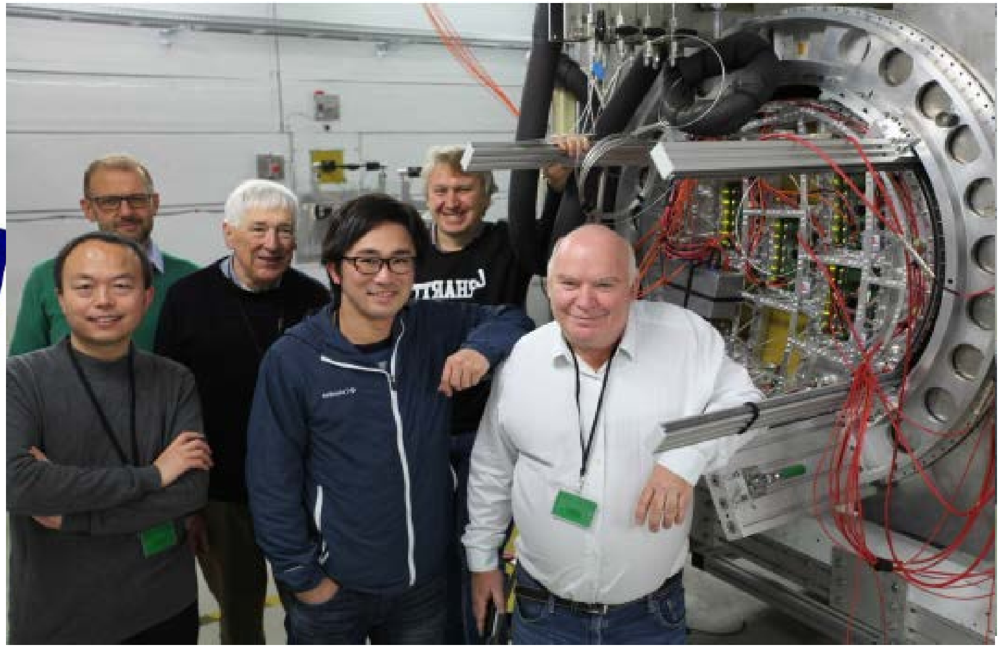
- **Resistive Micromegas has been studied by the beam under 1.0T.**
  - Bulk-Micromegas with 128 μm gap size between mesh and resistive layer.
- HV scheme of the module (ERAM) places grid on ground potential
  - Spatial resolution of $\sigma_{r\phi} \leq 100$ μm







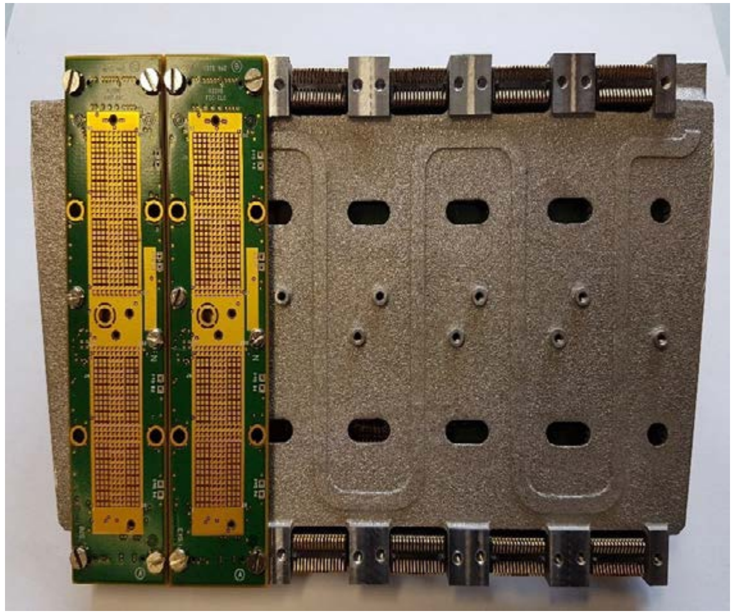


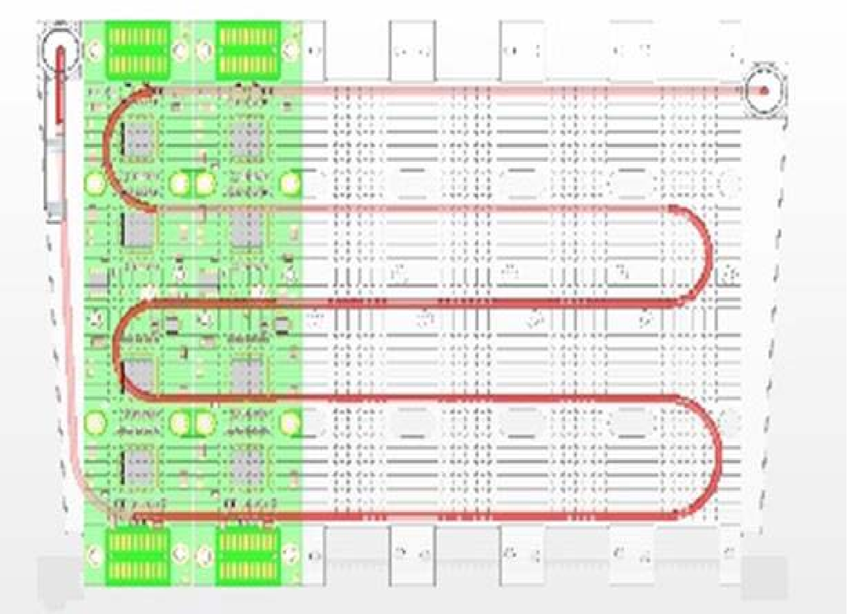


https://doi.org/10.1016/j.nima.2019.162798

Cooling system for readout electronics

- Readout electronics will require a cooling system. **2-phase CO_2-cooling** is a very interesting candidate.
  - A fully integrated AFTER-based solution tested on 7 Micromegas modules during a test beam.
- To optimize the cooling performance and the material budget **3D-printing of aluminum** is an attractive possibility for producing the complex structures required.
  - A prototype for a full module is **validated at LCTPC**.





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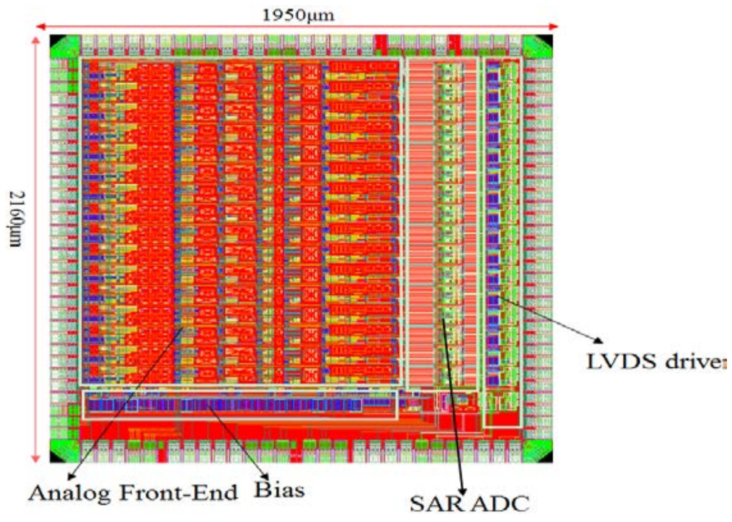
JINST 1018 (2022) 012149

- **Power consumption**
  - Pad readout TPC@1mm×6mm@IHEP
  - Total channels: **10^6**
  - Total power: <12 kW
    - 48mW/cm^2
    - WASA ASIC chip: 3.5mW/ch@40 MS/s



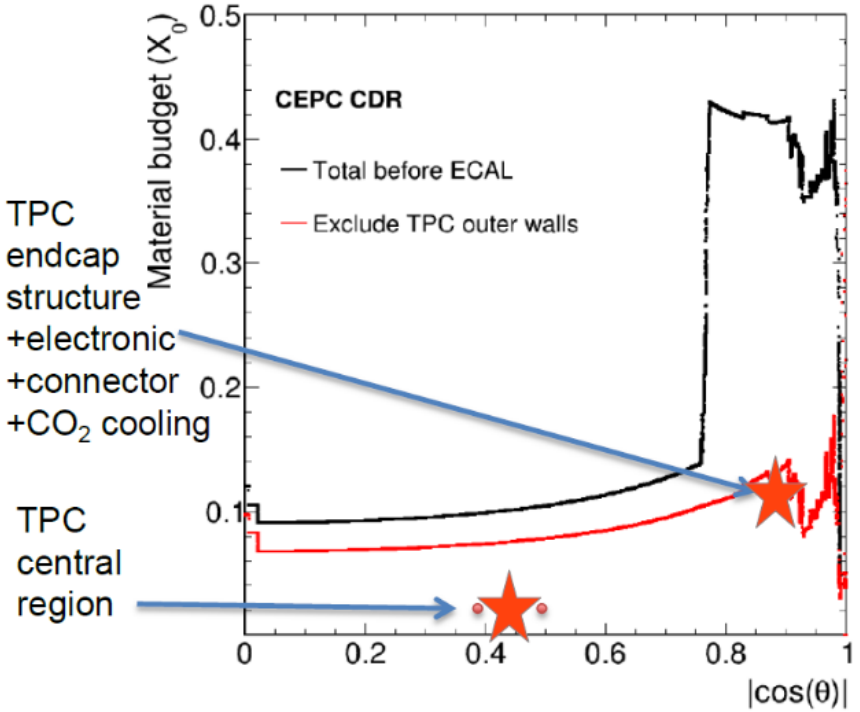
	AGET	PASA+ALTRO	Super-ALTRO	SAMPA
TPC	T2K	ALICE	ILC	ALICE upgrade
Pad尺寸	6.9x9.7 mm^2	4x7.5 mm^2	1x6 mm^2	4x7.5 mm^2
通道数	1.25 x 10^5	5.7x 10^5	1-2 x 10^6	5.7 x 10^5
读出结构	MicroMegas	MWPC	GEM/MicroMegas	GEM
增益	0.2-17 mV/fC	12 mV/fC	12-27 mV/fC	20/30 mV/fC
成型方式	CR-$(RC)^2$	CR-$(RC)^4$	CR-$(RC)^4$	CR-$(RC)^4$
达峰时间	50 ns-1us	200 ns	30-120 ns	80/160 ns
ENC	850 e @ 200ns	385 e	520 e	482 e @ 180ns
波形采样方式	SCA	ADC	ADC	ADC
采样率	1-100 MSPS	10 MSPS	40 MSPS	10 MSPS
精度	12 bit(external)	10 bit	10 bit	10 bit
功耗	<10 mW/ch	32 mW/ch	47.3 mW/ch	17 mW/ch
CMOS工艺	350 nm	250 nm	130 nm	130 nm

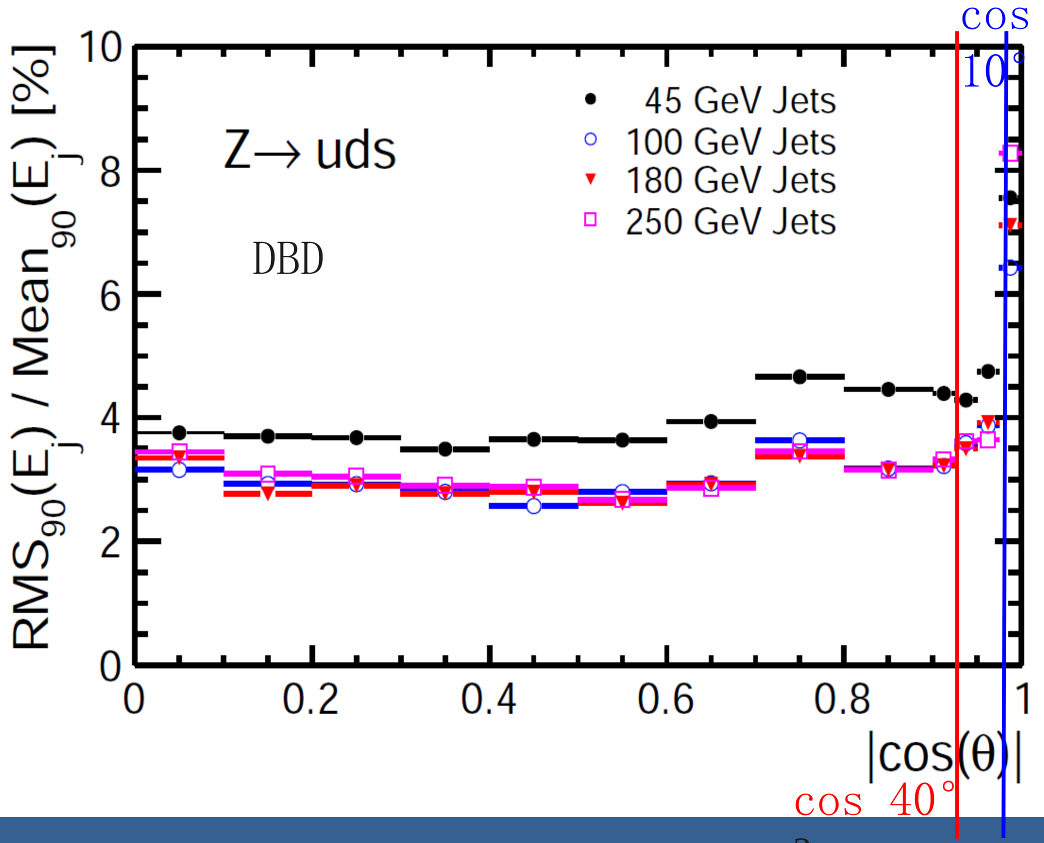
Material Budget – TPC – Very light

- **TPC as the main tracker detector**
  - A low material budget is a strong argument for a TPC
    - $\leq 5\%\ X_0$ in the barrel region
    - $\leq 25\%\ X_0$ in the endcap region
  - Increased material in endcap has no impact on jet energy resolution

	45 GeV	100 GeV	250 GeV
15%X_0	0.28±0.01	0.32±0.01	0.47±0.02
30%X_0	0.30±0.01	0.31±0.01	0.47±0.02
45%X_0	0.30±0.01	0.32±0.01	0.52±0.02
60%X_0	0.32±0.01	0.33±0.01	

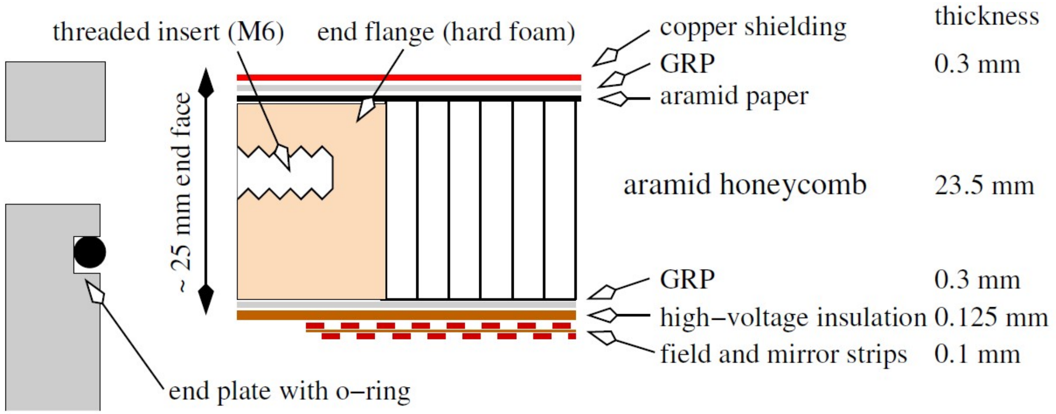
TPC – PRC2010 report



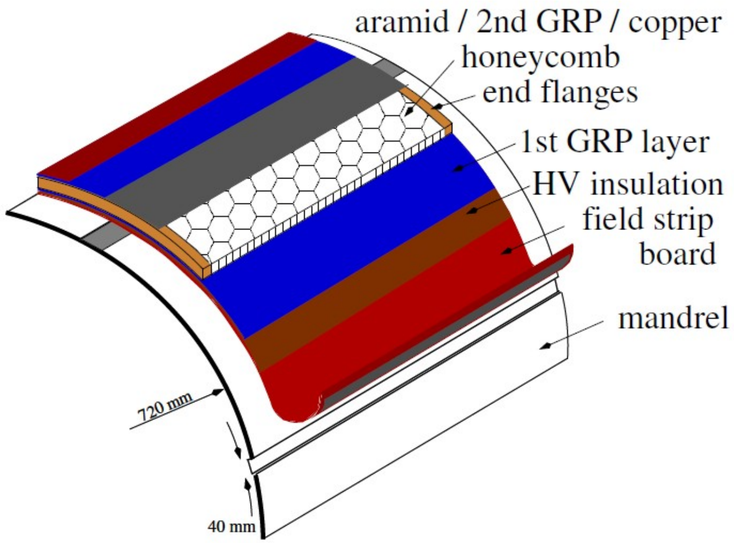


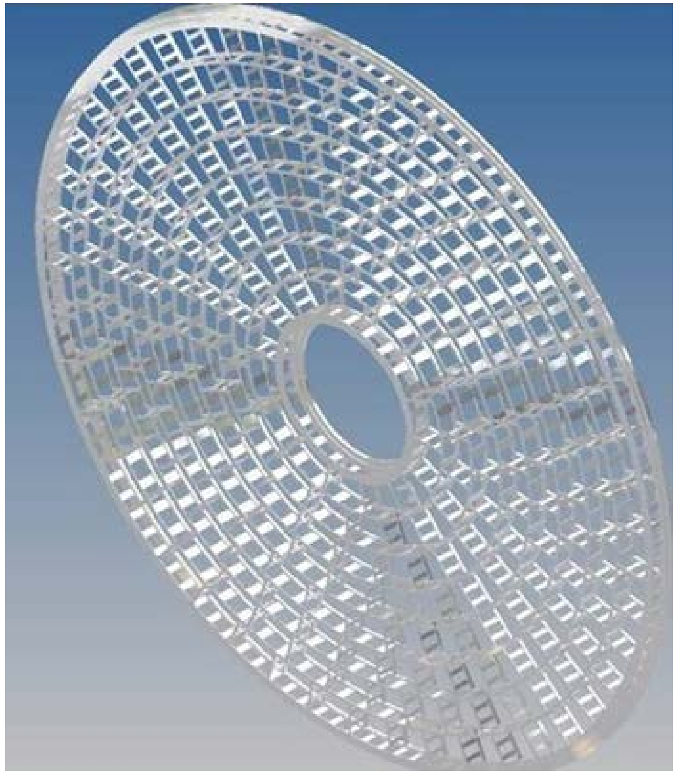
Material Budget – TPC – Validation

- Barrel of the material budget
  - Material budget of **1.2%X_0** was reached
  - Field homogeneity: $10^{-4} < \Delta E/E < 10^{-3}$
  - Operation gas (**negligible**): 1.2kg/m^3
- Endcap of the material budget
  - Readout plane, electronics, detector: <**5%X_0**
  - Cooling: <**2%X_0**
  - Power cables: <**10%X_0**



layer of the wall	d [cm]	X_0 [cm]	d/X_0 [%]
copper shielding	0.001	1.45	0.07
polyimide substrate	0.005	32.65	0.02
outer GRP	0.03	15.79	0.19
aramid paper	0.007	29.6	0.02
honeycomb	2.35	1383	0.17
inner GRP	0.03	15.79	0.19
polyimide insulation	0.0125	32.65	0.04
mirror strips	$0.8 \cdot 0.0035$	1.45	0.19
polyimide substrate	0.0050	32.65	0.02
field strips	$0.8 \cdot 0.0035$	1.45	0.19
epoxy glue	$\approx 6 \cdot 0.007$	≈ 35.2	0.12
		$\sum$	1.21





TPC as the main tracker

- **TPC as the main track detector for CEPC**
  - **Material budget of endplate/chamber √**
  - **Occupancy √**
  - **Optimization of pad size √**
  - **Channels and power consumption √**
  - **Cost estimation √**
  - **Ions affect and distortion √ (need R&D for Z pole)**
  - **Improved dE/dx+dN/dx √ (need R&D Z pole)**

Many thanks!